

## CHAPTER 6

### COMMUNICATING RISKS AND UNCERTAINTIES IN PROBABILISTIC RISK ASSESSMENTS

#### 6.0 INTRODUCTION

The Environmental Protection Agency (EPA) has developed a guidance document, *Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual, Supplement to Part A: Community Involvement in Superfund Risk Assessments* (U.S. EPA, 1999a) and two videotapes, “*Superfund Risk Assessment and How You Can Help, An Overview*” (10 minutes) (U.S. EPA, 1999b) and “*Superfund Risk Assessment and How You Can Help*” (40 minutes) (U.S. EPA, 2000b), to improve community involvement in the Superfund risk assessment process. The videotapes (available in both English and Spanish) show examples of how regions have involved communities in the risk assessment process at several Superfund sites. The guidance document and videotapes, along with the *Superfund Community Involvement Handbook and Toolkit* (U.S. EPA, 1998), should serve as a primary community involvement resource for risk assessors and remedial project managers (RPMs). The *Handbook and Toolkit* offers the following specific guidance:

- Provides suggestions for how Superfund staff and community members can work together during the early stages of Superfund remedial investigation and feasibility study (RI/FS) and later cleanup
- Identifies where, within the framework of the human health risk assessment methodology, community input can augment and improve EPA’s estimates of exposure and risk.
- Recommends questions the site team (risk assessor, RPM, and community involvement coordinator [CIC]) should ask the community.
- Illustrates why community involvement is valuable during the human health risk assessment at Superfund sites.

This chapter provides guidance and suggestions on how to deal with risk communication issues that arise during a probabilistic risk assessment (PRA). Specifically, the concepts of uncertainty and variability may present additional communication challenges for PRA. For example, whereas discussions of uncertainty for point estimate risk assessments are often qualitative in nature, PRA opens the floor for discussion and presentation of quantitative uncertainty analysis. Concepts associated with quantitative characterizations of uncertainty may be more difficult to communicate and may not be well received due to stakeholder desires for certainty (Slovic et al., 1979). As such, this chapter highlights appropriate stakeholder involvement and principal risk communication skills that are effective for communicating PRA concepts and risk information. Key factors for successful communication of PRA include early and continuous involvement of stakeholders, a well-developed communication plan, good graphics, a working knowledge of the factors that may influence perceptions of risk and uncertainty, and a foundation of trust and credibility.

EXHIBIT 6-1

DEFINITIONS FOR CHAPTER 6

Central Tendency Exposure (CTE) - A risk descriptor representing the average or typical individual in a population, usually considered to be the mean or median of the distribution.

Community Advisory Group (CAG) - A group formed to provide a public forum for community members to present and discuss their needs and concerns related to the Superfund decision-making process. A CAG serves as the focal point for the exchange of information among the local community, EPA, State regulatory agency, and other pertinent Federal agencies involved in the cleanup of a Superfund site.

Community Involvement Coordinator (CIC) - As a member of the CAG and site team, the CIC coordinates communication plans (i.e., the CIP) and addresses site-specific CAG organizational issues.

Community Involvement Plan (CIP) - A plan that identifies community concerns and the preferences of the community for the communication of site-related issues.

Confidence Interval - A range of values that are likely to include a population parameter. Confidence intervals may describe a parameter of an input variable (e.g., mean ingestion rate) or output variable (e.g., 95<sup>th</sup> percentile risk). When used to characterize uncertainty in a risk estimate, it is assumed that methods used to quantify uncertainty in the model inputs are based on statistical principles such as sampling distributions or Bayesian approaches. For example, given a randomly sampled data set, a 95% confidence interval for the mean can be estimated by deriving a sampling distribution from a Student's t distribution.

Credible Interval - A range of values that represent plausible bounds on a population parameter. Credible intervals may describe a parameter of an input variable (e.g., mean ingestion rate) or output variable (e.g., 95<sup>th</sup> percentile risk). The term is introduced as an alternative to the term confidence interval when the methods used to quantify uncertainty are not based entirely on statistical principles such as sampling distributions or Bayesian approaches. For example, multiple estimates of an arithmetic mean may be available from different studies reported in the literature—using professional judgment, these estimates may support a decision to describe a range of possible values for the arithmetic mean.

Cumulative Distribution Function (CDF) - Obtained by integrating the PDF, gives the cumulative probability of occurrence for a random independent variable. Each value  $c$  of the function is the probability that a random observation  $x$  will be less than or equal to  $c$ .

Hazard Quotient (HQ) - The ratio of estimated site-specific exposure to a single chemical from a site over a specified period to the estimated daily exposure level, at which no adverse health effects are likely to occur.

Hazardous Substance Research Centers (HSRC) - Research centers providing free technical assistance to communities with environmental contamination programs through two distinct outreach programs: Technical Outreach Services for Communities (TOSC) and Technical Assistance to Brownfields Community (TAB).

Histogram - A graphing technique which groups the data into intervals and displays the count of the observations within each interval. It conveys the range of values and the relative frequency (or proportion of the sample) that was observed across that range.

Monte Carlo Analysis (MCA) or Monte Carlo Simulation - A technique for characterizing the uncertainty and variability in risk estimates by repeatedly sampling the probability distributions of the risk equation inputs and using these inputs to calculate a distribution of risk values. A set of iterations or calculations from Monte Carlo sampling is a simulation. For example, a single iteration for risk from ingestion of water may represent a hypothetical individual who drinks 2 L/day and weighs 65 kg; another iteration may represent a hypothetical individual who drinks 1 L/day and weighs 72 kg.

Parameter - A value that characterizes the distribution of a random variable. Parameters commonly characterize the location, scale, shape, or bounds of the distribution. For example, a truncated normal probability distribution may be defined by four parameters: arithmetic mean [location], standard deviation [scale], and min and max [bounds]. It is important to distinguish between a variable (e.g., ingestion rate) and a parameter (e.g., arithmetic mean ingestion rate).

Percentile - A number in a distribution such that  $X$  % of the values are less than the number and  $1-X$  % are greater. For example, the 95<sup>th</sup> percentile is a number in a distribution such that 95% of the values are less than the number and 5% are greater.

EXHIBIT 6-1

DEFINITIONS FOR CHAPTER 6—Continued

Point Estimate Risk Assessment - A risk assessment in which a point estimate of risk is calculated from a set of point estimates for exposure and toxicity. Such point estimates of risk can reflect the CTE or RME, depending on the choice of inputs.

Potentially Responsible Party (PRP) - Individuals, companies, or any other party that is potentially liable for Superfund cleanup costs.

Preliminary Remediation Goal (PRG) - Initially developed chemical concentration for an environmental medium that is expected to be protective of human health and ecosystems. PRGs may be developed based on applicable or relevant and appropriate requirements (ARARs), or exposure scenarios evaluated prior to or as a result of the baseline risk assessment. (U.S. EPA, 1991a, 1991b).

Probabilistic Risk Assessment (PRA) - A risk assessment that yields a probability distribution for risk, generally by assigning a probability distribution to represent variability or uncertainty in one or more inputs to the risk equation.

Probability Density Function (PDF) - A function or graph representing the probability distribution of a continuous random variable. The density at a point refers to the probability that the variable will have a value in a narrow range about that point.

Rank Correlation (Spearman Rank Order Correlation Coefficient) - A “distribution free” or nonparametric statistic  $r$  that measures the strength and direction of association between the ranks of the values (not the values themselves) of two quantitative variables.

Reasonable Maximum Exposure (RME) - The highest exposure that is reasonably expected to occur at a site (U.S. EPA, 1989). The intent of the RME is to estimate a conservative exposure case (i.e., well above the average case) that is still within the range of possible exposures.

Remedial Investigation/Feasibility Study (RI/FS) - Studies undertaken by EPA to delineate the nature and extent of contamination, to evaluate potential risk, and to develop alternatives for cleanup.

Sensitivity Analysis - Sensitivity generally refers to the variation in output of a model with respect to changes in the values of the model’s input(s). Sensitivity analysis can provide a quantitative ranking of the model inputs based on their relative contributions to model output variability and uncertainty. Common metrics of sensitivity include:

- ▶ Pearson Correlation Coefficient - A statistic  $r$  that measures the strength and direction of linear association between the values of two quantitative variables. The square of the coefficient ( $r^2$ ) is the fraction of the variance of one variable that is explained by the variance of the second variable.
- ▶ Sensitivity Ratio - Ratio of the change in model output per unit change in an input variable; also called *elasticity*.
- ▶ Spearman Rank Order Correlation Coefficient - A “distribution free” or nonparametric statistic  $r$  that measures the strength and direction of association between the ranks of the values (not the values themselves) of two quantitative variables. See Pearson (above) for  $r^2$ .

Stakeholder - Any individual or group who has an interest in or may be affected by EPA’s site decision-making process.

Technical Assistance Grant (TAG) - A federal grant that is intended to provide a community with the opportunity to hire independent experts to help evaluate and explain the results of a risk assessment.

Technical Outreach Services for Communities (TOSC) - A service of the HSRC with the aim to provide independent technical information and assistance to help communities with hazardous substance pollution problems.

Uncertainty - Lack of knowledge about specific variables, parameters, models, or other factors. Examples include limited data regarding the concentration of a contaminant in an environmental medium and lack of information on local fish consumption practices. Uncertainty may be reduced through further study.

Variable - A quantity that can assume many values.

Section 6.1 discusses the need for early and continuing stakeholder involvement. Section 6.2 recommends a seven-step process for communicating PRA results to stakeholders, and Sections 6.3 and 6.4 provide guidance on specific techniques for communicating information. The success of risk communication efforts will depend on the extent to which the communication strategy addresses the needs of a diverse audience, with different perceptions of risk and uncertainty (Section 6.5), and the degree of trust and credibility that is established from the outset of the process (Section 6.6). Section 6.7 provides a discussion of risk communication issues that are uniquely relevant to RPMs.

## 6.1 STAKEHOLDER INVOLVEMENT

Many stakeholders may be interested in a risk assessment (see Exhibit 6-2). It is generally important to *involve and engage interested stakeholders early and continuously* throughout the decision-making process (U.S. EPA, 2001).

Public involvement activities should be tailored to the needs of the community and described in the site communications strategy. The CIC should coordinate these first steps through the development of a Community Involvement Plan (CIP). Coordination between the RPM, risk assessor, and CIC is needed to determine the appropriate points in the RI/FS process to communicate with the community, and plan for the appropriate level of communication. The CIP should identify community concerns and the preferences of the community for the communication of site-related issues. The CIP may be updated during the RI/FS as needed.

### EXHIBIT 6-2

#### STAKEHOLDERS POTENTIALLY INVOLVED IN THE DECISION-MAKING PROCESS FOR PRA

- EPA risk assessors and managers
- Members of the public
- Representatives from state or county environmental or health agencies
- Other federal agencies (e.g., health agencies, Natural Resources Damage Assessment (NRDA), trustees, etc.)
- Tribal government representatives
- Potentially responsible parties (PRPs) and their representatives
- Representatives from federal facilities (e.g., Department of Defense, Department of Energy, etc.)

Examples of outreach activities include giving oral presentations and poster sessions at public meetings, coordinating group meetings or focused workshops, conducting interviews with community members on specific issues, and distributing fact sheets.

Ideally, the public and other interested stakeholders would be involved early in the site-specific decision-making process. If the community has not been previously involved, efforts should be made, in coordination with the CIC, to identify and communicate with the appropriate individuals in the community prior to the Agency's receipt of the PRA workplan. The public and other stakeholders should be given the opportunity to provide input to the workplan for a PRA (see Chapter 2, Section 2.1).

The initial community meeting can serve to establish a rapport between EPA and the community and facilitate the exchange of information needed to support a PRA. This information may include policy decisions associated with both point estimate and probabilistic approaches, as well as technical details regarding the conceptual exposure model and the selection of distributions. A discussion of these topics may increase certainty about the assumptions made in the risk assessment. For example, the community may be able to offer insights regarding site-specific activities and sources of exposure data

not readily available to the risk assessor. This type of discussion should allow for the free exchange of information with the public and sets the stage for future discussions. It is important that an appropriate level of detail be presented at the first meeting. Instead of overloading the audience with information, it is generally better to coordinate several meetings so that complex policy and technical concepts can be broken down into smaller discussion topics.

Following the approval of the PRA workplan, the public and other interested stakeholders should be involved in various stages of the PRA development, including providing and/or reviewing data, reviewing the selected distributions (e.g., selected creel survey) and commenting on PRA documents as appropriate during public comment periods. On-going community involvement may require consideration of EPA's resources including the availability of personnel and contractor support. Other considerations include EPA's compliance with provision in the National Contingency Plan (NCP) for involving the community. The appropriate level of community involvement in the PRA should be based on a number of factors including the nature and extent of contamination at the site, the expressed interests of the community members, the complexity of the PRA, and the role of PRA in site-specific remediation or cleanup decisions.

## **6.2 COMMUNICATION AND PRESENTATION**

Communication is a two-way process that should involve the transfer of information between the Agency and the stakeholders, as well as active listening by the Agency to the stakeholder's ideas and concerns. The goals of risk communication are to present risk information in an understandable manner through an open, honest, frank, and transparent presentation and discussion of risks, including uncertainties. In meeting these goals, it is important that the RPMs and risk assessors be sincere and direct in their presentation of the results of the PRA, accept the public and other interested stakeholders as valuable contributors to the process, and listen to the concerns and ideas that are raised.

One goal of communication should be to respect the stakeholder's concerns. The public and other interested stakeholders should have the opportunity to understand the PRA and its effects on the decision-making process. Technical Assistance Grants (TAGs) may be one way to advance this goal by providing the community the opportunity to hire independent experts to help evaluate and explain the results of the PRA. Alternatively, the RPM and risk assessor may use the tools outlined in Sections 6.3 to 6.6 to present PRA concepts and the results of the PRA to the community in a manner that is easily understood. This may require significant up-front planning, testing, and post-evaluation to identify the appropriate messages to communicate and to determine how well this information was communicated.

The site-specific PRA communication plan should be consistent with the NCP's provisions on community involvement. It is important to recognize that community involvement is part of a regulatory process and that EPA generally will consider all timely public input, but may not implement all of it. Ultimately, EPA must meet the legal requirements of the Superfund law in making decisions regarding remedial actions.

A vast body of literature exists regarding risk communication. Since the early 1980's, a number of researchers have developed models for communicating risk to the public. These models are available in the scientific literature, and a list of supplemental references is provided at the end of this chapter.

### **6.2.1 COMMUNICATION OF PRA WITH CONCERNED CITIZENS, OTHER STAKEHOLDERS, AND MANAGERS: AN OVERVIEW**

Before the decision to conduct a PRA is made, a CIP should be in place. Generally, when a decision is made to conduct a PRA, an important step should be to work with citizens to develop a communication strategy for PRA and its application within the Superfund process (see Chapter 1). The initial introduction of the community to the RI/FS process should include a discussion of the principles of risk assessment. This discussion may be best presented in an informal setting such as a public availability session. Because of the potentially complex nature of PRA and quantitative uncertainty analysis, a small group meeting may be an appropriate forum in which to discuss issues and facilitate an exchange of ideas. If there is interest among a large group of stakeholders, multiple small group sessions may be scheduled. Such meetings may provide the foundation for building trust and credibility (see Section 6.6).

In general, it is important to identify whether a Community Advisory Group (CAG) should be formed. The purpose of a CAG is to provide a public forum for community members to present and discuss their needs and concerns related to the Superfund decision-making process. The CIC is an important member of the team and may coordinate communication plans, hand-out materials, and address site-specific organizational issues.

A number of resources may be available to the community to aid in understanding technical material in a PRA. In addition to the TAG program, which provides funds for qualified citizens' groups affected by a Superfund site to hire independent technical advisors, another program is the Technical Outreach Services for Communities (TOSC), which uses university educational and technical resources to help communities understand the technical issues involved in hazardous waste sites in their communities. This is a no-cost, non-advocate, technical assistance program supported by the Hazardous Substance Research Centers.

The tiered approach for PRA presented in Chapter 2 (Figures 2-1 and 2-2) encourages risk assessors and RPMs to participate in discussions with stakeholders early in the process of developing point estimate and probabilistic approaches. If a decision is made to perform a PRA, a continuing dialogue should be useful to evaluate interim results of the PRA and determine if additional activities are warranted (e.g., data collection, further modeling). These on-going discussions should help assure that RPMs are aware of the details of the PRA analysis and are comfortable with the material that will be shared with the community, other interested stakeholders, and senior managers.

## 6.2.2 STEPS FOR COMMUNICATION OF THE RESULTS OF THE PRA

The complexity of a PRA will vary depending on the site-specific nature of the assessment performed. For example, PRAs may include an analysis of variability, uncertainty, or both. Some analyses may involve simulations to evaluate temporal variability (e.g., Microexposure Event analysis) and spatial variability (e.g., geostatistics). The challenge for presenters is to *identify the critical information and level of detail to be presented to various audiences that may be involved in the Superfund decision-making process* (e.g., senior risk managers, concerned citizens, congressional staff, and PRPs).

The 7-step process, described below (and summarized in Exhibit 6-3), may be repeated many times during the performance of a PRA. For communication purposes, a PRA normally will involve more interaction with stakeholders than a point estimate risk assessment because PRA concepts and results are often more difficult to communicate.

### (1) *Identify the Audience*

The first step should be to identify the audience of potentially interested stakeholders. Strategies for presenting PRA information normally will be tailored to the audience. Participants in the audience may change during the tiered process depending on the complexity of the PRA (see Chapter 2) and the specific site-management decisions being made.

### (2) *Identify the Needs of the Audience*

The second step should be to identify the needs of the audience. The relevant information and the appropriate level of detail will vary depending on the audience. For example, some participants may be well informed about PRA concepts and will not need much introductory PRA information. For other audiences, PRA concepts may be new, so it may be beneficial to hold an informal meeting to discuss the general objectives and methods used to conduct a PRA. Once introductory PRA concepts have been discussed and are understood by the audience, more advanced discussions may be warranted on topics such as the sources of data used in the PRA, the most critical variables in the PRA (identified during the sensitivity analysis), the selection of distributions, and the level of characterization of uncertainty (see also Section 6.5). The risk assessor should select the key information for each topic and discuss the significance of this information based on the intended audience.

#### EXHIBIT 6-3

##### IMPORTANT STEPS FOR COMMUNICATING PRA RESULTS

- (1) Identify the audience
- (2) Identify the needs of the audience
- (3) Develop a communication plan
- (4) Practice to assure clarity of presentation
- (5) Present information
- (6) Post-meeting review of presentation and community feedback
- (7) Update information as needed for future assessments and presentations

**(3) Develop a Communication Plan**

The third step should be to develop a plan to communicate significant information to the public in an easily understandable format (Exhibit 6-4). Adequate planning in the presentation of PRA information is essential. A thorough understanding of the design and results of the PRA will help to place the information in proper context and understandable format (U.S. EPA, 1994). Even more importantly, the risk assessors and RPMs should clearly identify the main messages to be presented.

**EXHIBIT 6-4**

**KEY CONSIDERATIONS IN DEVELOPING  
UNDERSTANDABLE MATERIAL**

- Identify main messages
- Place information in appropriate context
- Use clear formats
- Use examples and graphs
- Provide handouts and glossaries
- Present information with minimum jargon

Section 6.4 provides examples of graphics that may be useful in presentations of PRA. Handouts, glossaries, and other materials may complement a presentation and provide information for discussion following the meetings. In addition, examples designed to help demonstrate concepts unique to PRA (e.g., using one probability distribution to describe variability and a second distribution to describe parameter uncertainty) may help facilitate the flow of communication and increase the level of understanding. One useful technique in public meetings is to involve members of the audience to illustrate a concept. For example, the topic of discussion may be the method used to select and fit a probability distribution used to characterize variability in a PRA. To demonstrate this concept, a risk assessor can draw a bell-shaped curve on a flip chart and label the *x-axis*, “number of liters of water consumed per day”, and the *y-axis*, “number of people who consume a specific amount of water in a day”. Next, each meeting participant can be asked to identify their own consumption pattern, perhaps by holding up a 0.5 liter bottle and asking how many such bottles are consumed on an average day. This community-specific information can then be plotted on a new graph in the form of a histogram and the bars can be connected to form a curve or distribution similar to the one first drawn. The resulting distribution (for an example, see Figure 6-1) can then be used to discuss the following PRA concepts in more detail:

- Variability (between individuals)
- Shape of the distribution and plausible range of values
- Central tendency exposure (CTE) and reasonable maximum exposure (RME) estimation
- Uncertainty in the distribution (sample size, potential response bias, differences in activity patterns)
- Uncertainty in a parameter estimate (difference between the 95% upper confidence limit (UCL) for a mean and the 95<sup>th</sup> percentile)

Using this information as a basis, the risk assessor can compare the results from the community analysis with data from various geographic areas in the U.S. where water consumption patterns may differ. The risk assessor can then lead a discussion with the community regarding the various sources of uncertainty in selecting and fitting exposure distributions, including:

- (a) **Extent of Representation** - Are the available data representative of the target population? For example, would the data on water consumption collected during the meeting be representative for various population groups?



- (b) **Data Quantity** - What sample size is needed to develop a distribution? This discussion will introduce the concept that uncertainty in both point estimates and probability distributions may be reduced by increasing the sample size
- (c) **Data Quality** - Are the data collected using acceptable study protocols? Is the information available from the peer-reviewed literature? An example can be made of the data collected during the meeting to highlight issues associated with survey design, and methods for controlling for potential bias or error. For example, if the survey data were to be used in a risk assessment for a drinking water scenario, the data quality may be improved by repeat sampling over time

Other exposure variables that can be used in this distribution example include: fish consumption rates, chemical concentrations in soil, and fraction of time spent indoors. In general, examples should focus on variables that may be of interest, are easily illustrated, and are unlikely to make participants uncomfortable divulging personal information such as age.

#### **(4) Practice to Assure Clarity of Presentation**

The fourth step should be to practice the presentation to assure that the information is presented clearly to the intended audience. Staff from communication groups or public information offices within EPA regional offices may help to determine whether or not the presentation addresses the needs of various audiences. Also, practicing the presentation with co-workers who are unfamiliar with the site can help assure that the appropriate messages are being conveyed, and will help the team prepare for potential questions that will arise during the meeting.

#### **(5) Present Information**

A number of factors should be considered when developing a plan to present the PRA in a meeting. Although the size of the public meeting can sometimes be unpredictable, typically individuals will feel more comfortable asking questions and expressing opinions in small, informal settings. For any audience, it is usually helpful to have general fact sheets on PRA available for distribution. The fact sheets may contain information that describes the PRA process, how information from the PRA will be used at the site, and how the community may comment on the PRA report. The meeting team should usually include the CIC, RPM, Risk Assessor, and additional support as necessary.

Audio-visual materials and equipment should be checked prior to the start of the meeting. For example, overheads should be viewed from the audience seating to assure that information is accessible and readable. Presentations using portable computers can be effective for showing how the results of the PRA may differ with changes in modeling assumptions.

#### **(6) Post-meeting Review of Presentation and Community Feedback**

At the end of a meeting, it can be helpful to encourage participants to provide feedback regarding effective and ineffective communication techniques. Not only can this information be used to improve presentations offered to similar audiences in the future, it also provides a sense for how well the main messages and specific technical issues were communicated.

**(7) *Update Information as Needed for Future Assessments and Presentations***

Shortly after the meeting or briefing, modifications should be made to the materials for future presentations where appropriate. In addition, if information is obtained that is relevant to the risk assessment, this information may be included in a subsequent analysis, and the process would be repeated.

**6.3 COMMUNICATING DIFFERENCES BETWEEN POINT ESTIMATE AND PRA**

One method for effectively explaining the PRA approach to quantifying variability and uncertainty is to employ comparisons to the more easily understood point estimate methodology. These comparisons can focus on either the inputs or the outputs associated with the two approaches. The communicator may focus on a specific input variable, such as drinking water intake, and explain that with the point estimate methodology, a single average or high-end value (e.g., 2 liters per day for adults) normally is used to quantify exposure, whereas with PRA, a probability distribution (e.g., lognormal) is used to characterize variability in exposure among a population. In addition, the outcomes (e.g., cancer risk estimates) can be compared by showing where the point estimate(s) of risk fall within the distribution of risks generated with PRA.

When communicating results from point estimate and PRA models, an important concept to keep in mind is that both methods yield risk estimates with varying degrees of uncertainty. Continuing with the above example, concepts associated with uncertainty (e.g., representativeness, data quantity, and data quality) can be introduced by asking the audience if their estimate of water consumption on a specific day would be equal to their average daily consumption rate over a 1-year period. This example highlights a common source of uncertainty in exposure data (i.e., using short-term survey data to estimate long-term behavior). Section 6.5 discusses different perceptions of uncertainty.

It is common to accept output from quantitative models without fully understanding or appreciating the corresponding uncertainties and underlying assumptions. One challenge in presenting PRA results is to determine the most effective way to communicate sources of uncertainty without undermining the credibility of the assessment (see Section 6.6). For example, it may be counterintuitive that the more sources of uncertainty that are accounted for in a PRA, the wider the confidence intervals tend to be in the risk estimates (see Section 6.4.2). The audience may question the utility of a method that appears to introduce more complexity in a risk management decision. It may be useful to point out that many sources of uncertainty are present, and methods available to acknowledge and quantify them may differ in point estimate and probabilistic risk assessments.

The basic concepts of PRAs described in Chapter 1 may be used in developing presentations. Exhibits 1-5 and 1-6 in Chapter 1 summarize some of the advantages and disadvantages of point estimates and probabilistic approaches that should be considered when evaluating differences in the risk estimates of the two approaches. For example, point estimates of risk do not specify the proportion of the population that may experience unacceptable risks. In contrast, PRA methods allow statements to be made regarding both the probability of exceeding a target risk, and the level of confidence in the risk estimate.

When summarizing results of PRA, graphs and tables generally should include the results of the point estimates of risk (e.g., CTE and RME). It may be informative to note where on the risk distribution each of the point estimates lies. By understanding the assumptions regarding the inputs and modeling

approaches used to derive point estimates and probabilistic estimates of risk, a communicator will be better prepared to explain the significant differences in risk estimates that may occur. Special emphasis should be given to the model and parameter assumptions that have the most influence on the risk estimates, as determined from the sensitivity analysis (see Appendix A).

## **6.4 GRAPHICAL PRESENTATION OF PRA RESULTS TO VARIOUS AUDIENCES**

Graphics can be an effective tool for communicating concepts in PRA. As the old adage goes, “A picture is worth a thousand words.” A graphic usually can be most easily understood by a diverse audience when it conveys a single message. It is generally a good idea to keep the graphics simple so that the message is clear. In general, each graphic should be developed and modified depending on the type of presentation and the intended audience.

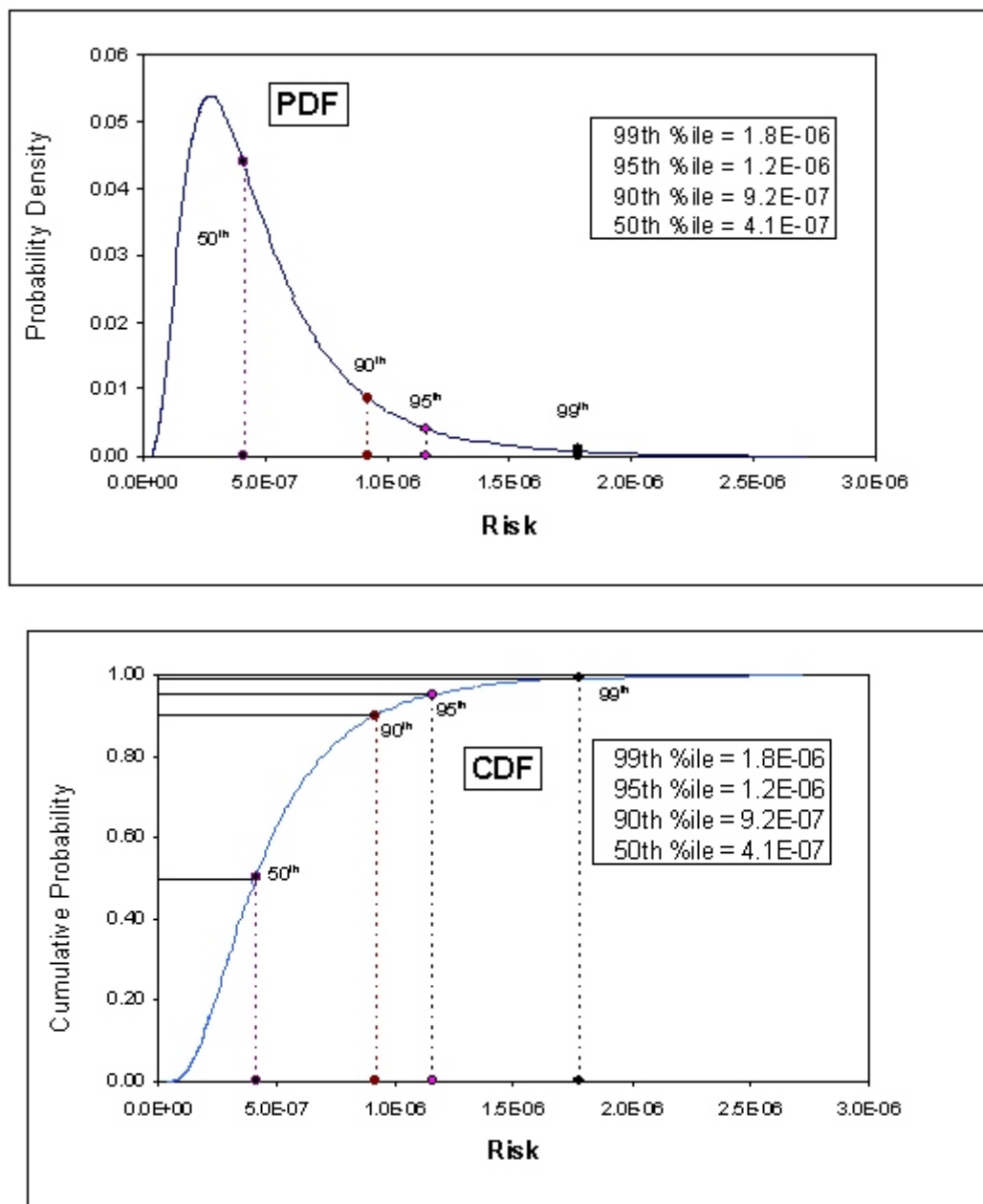
*☞ The key to presenting graphics in PRA effectively is to select a relatively small number of appropriate messages, and to find a balance between meaningful information and overwhelming detail.*

Points to consider when developing graphics for public meetings, senior staff, and the press are presented below. Certainly, recommendations for presenting clear and informative graphics are applicable to all three forums. Practical recommendations for graphical analysis techniques and tips for successful visual displays of quantitative information are given by Tufte (1983) and Helsel and Hirsch (1993).

### **6.4.1 PUBLIC MEETING**

For a public availability session (or meeting), care should be taken to assure that the graphics are of appropriate size and the lettering is easy to read. For example, a graphic on an 8 ½ x 11 inch sheet of paper, or a font size smaller than 18 pt in a computer presentation, may not be easily seen from the back of a large auditorium. It may be appropriate to present information using large posters, spaced so that the audience may move among them and discuss the posted results with the risk assessor or RPM. Handouts and a glossary of terms may also be used. Using slides with too much text should be avoided, since the information may be difficult to read and understand. Pre-planning and pilot testing the graphics before the presentation may be helpful in assuring that the message is accurately portrayed to the community.

Consistent with EPA’s guidance on risk characterization, the CTE and RME cancer risks and noncancer hazards, and EPA’s decision point should be highlighted on graphics. The discussions accompanying the graph should emphasize that these values represent risks to the average and high-end individuals, respectively, and serve as a point of reference to EPA’s decision point. The distribution of risks should be characterized as representing variability among the population based on differences in exposure. Similarly, graphics that show uncertainty in risk can be described using terms such as “confidence interval”, “credible interval”, or plausible range. The graphics need not highlight all percentiles. Instead, selected percentiles that may inform risk management decisions (such as the 5<sup>th</sup>, 50<sup>th</sup>, 90<sup>th</sup>, 95<sup>th</sup>, and 99<sup>th</sup> percentiles) should be the focus. Figure 6-1 shows an example of a PDF for variability in risk with an associated text box for identifying key risk percentiles.



**Figure 6-1.** Hypothetical PRA results showing a probability density function (PDF) (top panel) for cancer risk with selected summary statistics for central tendency and high-end percentiles. This view of a distribution is useful for illustrating the shape of the distribution (e.g., slightly right-skewed) and explaining the concept of probability as the area under a curve (e.g., most of the area is below 1E-06, but there is a small chance of 2E-06). Although percentiles can also be overlayed on this graphic, a cumulative distribution function (CDF) (bottom panel) may be preferable for explaining the concept of a percentile.

Figure 6-2 gives two examples of graphics that can be used to display results of a sensitivity analysis from a Monte Carlo Analysis (MCA). While both graphics are likely to be understood by non-technical audiences, the pie chart may be more familiar. The pie chart (Figure 6-2A) suggests that the results should sum to 1.0, which may not be true if there are correlations among one or more variables, or if only a subset of the variables are displayed (e.g., those that contribute at least 1%). The available data can be normalized so that the squared correlation coefficients do sum to 100%, and this approach has been adopted by some commercial software available to run Monte Carlo simulations (e.g., *Crystal Ball*® by Decisioneering, [www.decisioneering.com](http://www.decisioneering.com)). The benefit of showing the squared correlation coefficient ( $r^2$  or *r-square*, also called the coefficient of determination), rather than the correlation coefficient ( $r$ ) is that *r-square* is proportional to the total variation in risk associated with specified input variable. Therefore, one can use the *r-square* to describe, in quantitative terms, the contribution of the input variable to the total variance in the risk distribution. In this example, exposure duration (ED) contributes approximately two-thirds (64%) to the total variance in risk.

A more technical graphic is the tornado plot (Figure 6-2B). In addition to showing the relative magnitude of the correlations (*r-square*), it illustrates the direction of influence a specific variable has on the final risk estimate. Bars that extend to the right indicate a positive correlation (e.g., high risk estimates correspond with high values for the variable), whereas bars that extend to the left indicate a negative correlation (e.g., high risk estimates correspond with low values for the variable.) In this example, the exposure duration (ED) has the largest positive correlation with risk, while body weight (BW) has the largest negative correlation with risk.

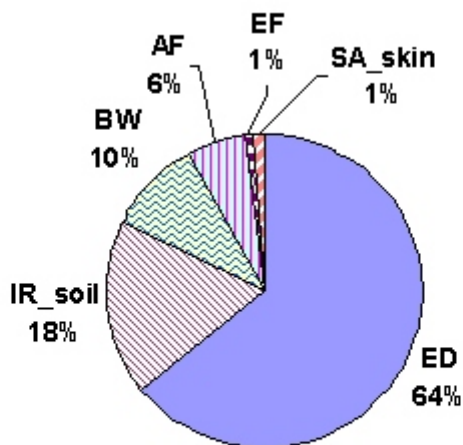
The graphics shown in this chapter are a small fraction of the graphics that might be used to communicate concepts related to PRA. Numerous additional examples are given throughout this guidance document. Table 6-1 provides a summary of cross references to other figures that were developed for this guidance document to convey specific concepts regarding variability and uncertainty.

**Table 6-1.** Examples of Graphics for Communicating PRA Concepts in this Guidance Document.

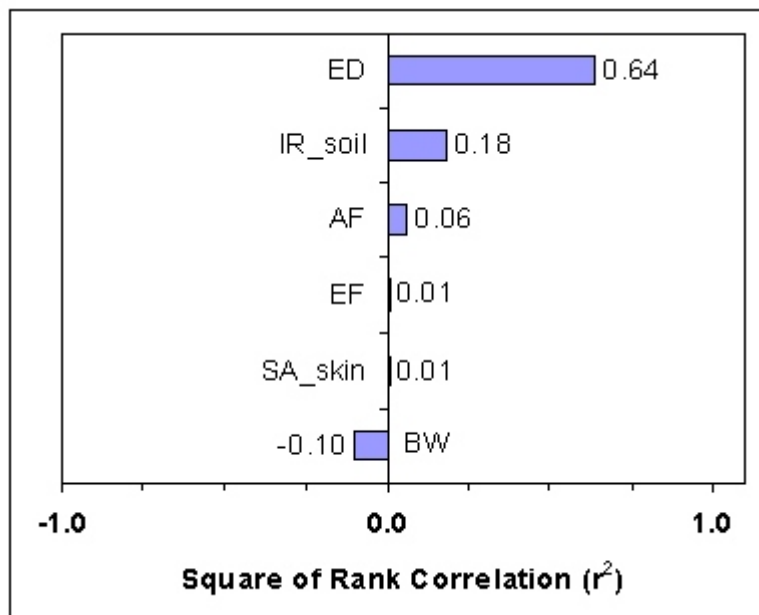
General PRA Topic Area	Location	Variability	Uncertainty
<b>Conceptual Diagrams for Fundamental Concepts</b>			
Monte Carlo Analysis	Figure 1-2	X	
Tiered process for PRA	Figure 2-1, 2-2	X	X
<b>PDFs and CDFs</b>			
Input variable(s)	Figure 1-1, 4-4, 4-5, 4-6	X	
Risk distribution with selected percentiles highlighted	Figure 6-1		X
Comparing RME risk (e.g., 95 <sup>th</sup> percentile) with risk level of concern	Figure 1-3, 4-3, 7-2,	X	
<b>Selecting and Fitting Probability Distributions</b>			
Fitting distributions - frequency distribution overlaid by a PDF	Figure 3-1	X	
Lognormal probability plot	Figure 5-2	X	
<b>Sensitivity Analysis</b>			
Sensitivity analysis - tornado plot of Spearman rank correlations	Figure 3-6, 6-2b	X	
Sensitivity analysis - pie chart	Figure 6-2a	X	
Joint probability curve	Figure 4-8	X	
<b>Variability in toxicity</b>			
Species sensitivity distribution	Figure 4-7	X	
<b>Iterative Simulations</b>			
CDFs from multiple 1-D MCA simulations to convey uncertainty in the risk distribution	Figure 3-3		X
<b>PRG Selection</b>			
Estimation from best-fit line for RME risk and EPC	Figure 5-1	X	
RME risk ranges corresponding to alternative choices of PRG	Figure 7-4	X	
90% credible interval for RME risk (95 <sup>th</sup> percentile) corresponding to alternative choices of PRG	Figure 7-5		X

Bi-model distribution for concentration showing pre-remediation EPC, post-remediation EPC, remediation action level, and uniform distribution for clean fill	Figure 5-3	X	X
<b>2-D MCA Results</b>			
Illustration of tabular and graphic outputs of a 2-D MCA	Figure 4-9		X
Confidence intervals (or credible intervals) on a risk distribution	Figure 1-4, 4-10, 4-11, 4-12		X
Box-and-whisker plot for results of 2-D MCA	Figure 3-4, 7-3		X
Horizontal box-and-whisker plots with multiple CDFs	Figure 6-3	X	X

**A. Pie Chart**



**B. Tornado Plot**

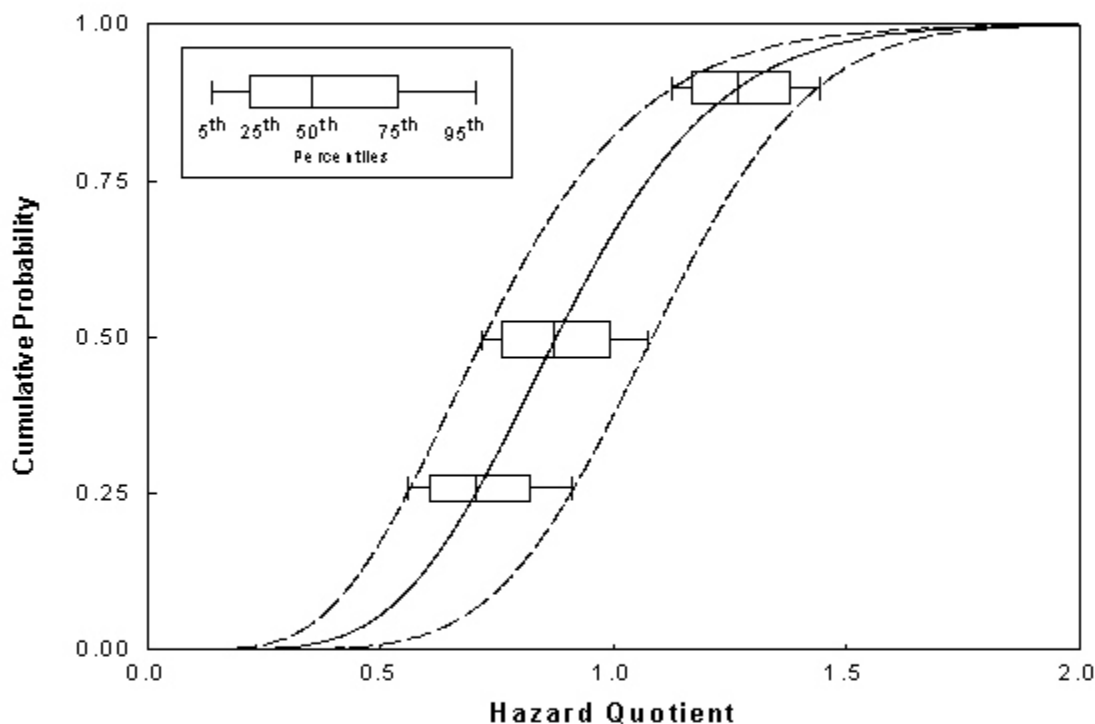


**Figure 6-2.** Results of a sensitivity analysis shown as a pie chart (A) and tornado plot (B). Both graphics illustrate the concept of the relative contribution to variance for exposure variables that contribute at least 1% to the variance in risk. The pie chart suggests that the sum of the squared rank correlations equals 1.0, which is true only if the results are normalized to 100%. The tornado plot gives both the magnitude and direction (positive or negative) of the correlation. ED=exposure duration, IR\_soil=soil ingestion rate, AF=absorption fraction, EF=exposure frequency, SA\_skin=surface area of skin, and BW=body weight.



## 6.4.2 EPA SENIOR STAFF

For communicating PRA with EPA's senior risk managers (e.g., EPA Section Chiefs, EPA Branch Chiefs, or EPA Division Directors), an executive summary or executive briefing package may be appropriate. This presentation should highlight major findings, compare point estimate and probabilistic results, provide sensitivity analysis results, and state uncertainties addressed in the PRA.



**Figure 6-3.** The results of a 2-D MCA. The graphic shows a method of presenting variability as a cumulative distribution function and uncertainty as box plots at the 25<sup>th</sup>, 50<sup>th</sup>, and 95<sup>th</sup> percentiles of variability. The CDF of the 50<sup>th</sup> percentile is represented by the solid line and the CDFs given by the dotted lines represent the 5<sup>th</sup> and 95<sup>th</sup> percentiles of uncertainty for each percentile of variability.

EPA senior level risk managers would generally be most interested in the risk estimates at the 50<sup>th</sup>, 90<sup>th</sup>, 95<sup>th</sup>, and 99.9<sup>th</sup> percentiles (i.e., a CTE risk estimate and the RME risk range). EPA senior managers may also wish to know the uncertainty surrounding each of the percentiles of risk. This uncertainty can be described in a table (e.g., confidence intervals around the 95<sup>th</sup> percentile risk) or a graphic (e.g., box-and-whisker plots). It is advisable for the risk assessor to have this information on hand during the briefing to respond to questions. Presenting distributions of uncertainty along with distributions of variability can create a very busy figure or table—it is best to keep things simple.

Figure 6-3 shows cumulative distribution functions (CDFs) for the Hazard Quotient (HQ) for a single chemical, representing variability in HQ. One method of displaying uncertainty is to use box-and-whisker plots. In this example, the horizontal box and whiskers represent uncertainty around selected percentile estimates of variability. Specifically, the three box-and-whisker plots correspond to the 25<sup>th</sup>, 50<sup>th</sup>, and 95<sup>th</sup> percentiles of the distribution for variability in HQ. The box shows the 25<sup>th</sup> and 75<sup>th</sup> percentiles (i.e., interquartile range) of uncertainty, whereas the whiskers show the 5<sup>th</sup> and 95<sup>th</sup> percentiles of uncertainty. In this example, uncertainty in the 95<sup>th</sup> percentile HQ is quantified by the box-and-whiskers plot in which the 5<sup>th</sup> percentile of uncertainty is 1.1, the 50<sup>th</sup> percentile is 1.3, and the 95<sup>th</sup> percentile is 1.4. This suggests that despite the uncertainty in the estimate of the 95<sup>th</sup> percentile of variability, an HQ of 1.0 is likely to be exceeded. Sometimes such results are said to describe the 90% *confidence interval* in the 95<sup>th</sup> percentile HQ. The term “confidence interval” is used loosely in this context to convey information about uncertainty; however, it is not the same as a statistical confidence limit that one might obtain by estimating a population parameter from a sample. An alternative term that may be more appropriate in this case is “credible interval”.

The three curves represent similar information on uncertainty across the complete range of percentiles for variability. The solid line shows the CDF for all of the 50<sup>th</sup> percentiles of uncertainty, whereas the dotted lines show the 5<sup>th</sup> and 95<sup>th</sup> percentiles of uncertainty.

The box-and-whisker plot is simple to produce, conveys information about the symmetry and width of the confidence interval, and is easy to interpret (Tufte, 1983). In general, box-and-whisker plots are useful for summarizing results from two-dimensional Monte Carlo (2-D MCA) simulations. The methods and inferences associated with 2-D MCAs are discussed further in Appendix D. The results of a 2-D Monte Carlo simulation represent a range of possible estimates for the percentile given one or more sources of uncertainty that were included in the simulation. If the target audience for this graphic has a greater understanding of statistics, it may be less confusing if alternative phrases are used to describe the results, such as “credible interval” or “probability band”.

Graphics that show probability density functions for uncertainty (PDFu's) are generally more meaningful to a technical audience of risk assessors and uncertainty analysts. Alternative graphics may be needed to communicate other sources of uncertainty in risk estimates (e.g., use of alternative probability models for exposure variables, effect of changes in the model time step, application of spatial weighting to concentration data, etc.). Additional information on communicating risks to senior EPA managers is given by Bloom et al. (1993).

The results from the sensitivity analysis may be useful to the senior managers in deciding whether additional sampling is necessary. One issue that may be important to address with risk managers and senior staff is that the width of the credible interval (e.g., 5<sup>th</sup> to 95<sup>th</sup> percentiles of uncertainty) will be determined in part by the number of sources of uncertainty that are quantified. As additional sources of uncertainty are quantified and included in the model, the interval around the risk distribution will tend to widen. This situation may appear to be counterintuitive for those managers who expect confidence to increase as uncertainty is quantified. However, by uncovering and quantifying the sources of uncertainty, the benefits in the risk communication and decision-making process should become clear. The results of the sensitivity analysis should help to focus discussions, data collection efforts, and analyses on the more significant sources of uncertainty. In addition, by developing estimates of credible intervals of uncertainty in risk estimates, the decision-making process using the tiered approach may become more transparent.

### 6.4.3 PRESS RELEASES

For a press briefing presentation, care should be given to identify messages and develop publication quality graphics with clear descriptions that can be provided in press packages. It is usually a good idea to provide the graphics in both color and black and white so that the press can choose the most appropriate presentation style for the story. The RPMs generally should work with the CIC, the press staff in the Communication Division, and senior managers to develop press materials. Adequate time should be left for the preparation of materials and internal Agency review and approval before information is released.

## 6.5 PERCEPTION OF RISK AND UNCERTAINTY

The purpose of this section is to present current thinking about how people view risk and uncertainty. This section should provide useful information for planning risk communication and addresses the first step in the seven step process (Section 6.2.2), “Identify the Audience.”

There are many individual differences in the way people regard the risks and hazards that are present in modern life. These differences have their roots in the differences in perception of risk and uncertainty of the individual human mind (Slovic, 1986). The risk assessor and/or risk communicator should keep in mind the general perceptions about risk held by different groups. Communications should be tailored to the specific audience. This section summarizes some of the criteria used to judge risks in the absence of scientific data and the direction of the potential bias that may be expected by applying these criteria. Additional publications on this issue are identified in the reference section at the end of this chapter.

In the absence of scientific data, the general public evaluates risks using inferences of judgment as described below (Slovic et al., 1979):

- **Availability:** People tend to judge risks as more likely if they are easy to recall.
- **Overconfidence:** People tend to be overconfident about the judgments they make based on the use of heuristics.
- **Desire for Certainty:** People tend to misgauge risk/benefit conflicts in favor of the benefits as a result of a desire for certainty and anxiety about uncertainty.

Slovic et al. (1979) identified nine characteristics of risk that may influence perceptions. These nine dimensions may provide a perspective on whether a health risk is perceived as “more risky” or “less risky”, as described in the table below.

<b>Dimension of Risk</b>	<b>More Risky</b>	<b>Less Risky</b>
Voluntariness	Involuntary	Voluntary
Immediacy of the effect	Delayed	Immediate
Exposed persons’ knowledge about risk	Low	High
Sciences’ knowledge about risk	Low	High
Control over risk	Low	High
Newness	Unfamiliar or New	Familiar
Chronic/Catastrophic	Catastrophic	Chronic
Common/Dread	Dreaded	Common
Severity of the consequences	High	Low

The presentation of uncertainty in a risk estimate can be interpreted with vastly different conclusions depending on the audience and their perceptions. For example, a thorough scientific account of multiple sources of uncertainty presented to a group of interested risk assessors and environmental scientists may be clearly understood. Such a group will likely conclude that the assumptions made in the risk assessment were appropriate and that the results can be used with confidence as a decision support tool. In contrast, a similar scientific presentation given to the community may be misunderstood, and the perceived risk may be greater. Citizens are often more concerned about the potential impact to their personal situation, than to the uncertainty in the risk estimate. Consequently, the community may react negatively to a long, highly scientific presentation on uncertainty. A good rule of thumb is to limit the presentation to no more than 15 minutes.

Focusing heavily on uncertainty may cause citizens to conclude that the risk must be high. They may also conclude that the presenter is incompetent because he or she is not sure of anything, or that the presenter is trying to hide something by cloaking the information in technical jargon, or even that the presenter is intentionally avoiding the public’s issues of concern. To the extent possible, technical jargon during the presentation should be avoided or explained.

A helpful presentation generally should incorporate the following steps: (1) present information about the conclusions that can be drawn from the risk assessment; it is extremely frustrating for decision-makers to receive detailed information on uncertainty without conclusions (Chun, 1996); (2) describe the certainty of the information that supports these conclusions; (3) address the uncertainty and its implications for the conclusions; and (4) present the information without jargon and in a frank and open manner. Section 6.4 provides examples of graphics that may be useful in presentations of PRA.

## **6.6 TRUST AND CREDIBILITY**

The single most important quality a presenter may need to possess in order to communicate to others is a sense of trust and credibility. Trust and credibility are based on working with the community and providing thoughtful, accurate responses to questions and concerns raised by the community. Building trust and credibility is important, whether communicating to a high-level technical audience, a RPM/decision-maker who wishes to have the "big picture," or the public.

Credibility can best be established through a long history of frank and open discussions with the community. In addition, a presenter can gain credibility if he or she has the ability to restate the available information so that it addresses the concerns and interests of an audience. The ability to garner trust and credibility comes from knowing the audience, respecting their opinion, and communicating at an appropriate level (U.S. EPA, 1994).

## **6.7 COMMUNICATION ISSUES FOR RPMs**

Following the RPM's decision to conduct a site-specific PRA, the level of stakeholder involvement in the development and review of the PRA should be evaluated. Establishing the appropriate level of stakeholder involvement may include input from the CIC, risk assessor and appropriate senior managers (e.g., Section Chief, Branch Chief, etc.). The level of stakeholder involvement may vary depending on the site complexity and the interest of the community. As an initial step, it may be appropriate to conduct an exploratory session where letters are sent to various stakeholders (e.g., environmental groups, CAG, etc.) inviting their participation in a general meeting on the topic of PRA. If there is a strong interest among the stakeholders, then a more involved communication plan may be appropriate including, but not limited to the following steps:

- Providing stakeholders with an introduction to the principles of PRA in an informal session (e.g., public availability session).
- Providing a draft Scope of Work (SOW) to interested stakeholders followed shortly thereafter by an availability session to discuss comments on the document.
- Providing a period of time for the stakeholders to review and comment on the selected distributions, including an availability session for discussions with EPA staff where the community may help to identify key site-specific information such as exposure factors and receptor behavior.
- Providing the opportunity for EPA risk assessor to meet with the TAG grantee (if appropriate) and stakeholders to ask questions regarding the SOW.
- Providing a revised SOW including a response to stakeholder comments.

- Providing an overview of the final PRA at a public meeting and providing appropriate supporting PRA documents in the repositories for stakeholder review and comment. This session may be part of the general session regarding the remedial investigation when the risk assessment is discussed. Based on the complexity of the PRA, it may be appropriate to hold a public availability session where the stakeholders (including the TAG grantee), if appropriate, are able to meet with EPA staff to ask questions and offer suggestions regarding the document.
- Providing a response to comments from stakeholders regarding the PRA.

If the level of interest is low, then a less extensive CIP may be appropriate. In this case, fact sheets (in plain language) describing the general principles of PRA to the stakeholders and the key findings of the PRA may be provided (U.S. EPA, 2000a). At public meetings where the risk assessment is discussed, a short discussion of the PRA findings and their significance may be appropriate. The PRA document should be made available in the repositories for review and comment by the stakeholders.

For sites with medium interest, a combination of the activities identified above may be appropriate. For example, it may be appropriate to have a public availability session on the principles of PRA and then make the documents available for review and comment.

The RPM should consider a number of administrative issues in developing the plan for involving the stakeholders in the PRA. Issues to consider include: staff resources, funds for obtaining meeting space, availability of contractor support, significance of PRA in decision making, and the length of time required to complete the RI/FS. To aid in reducing costs, it may be appropriate to combine meetings regarding PRA and point estimate risk assessment based on the close links between the documents.

## REFERENCES FOR CHAPTER 6

- Bloom, D.L. et al. 1993. Communicating Risk to Senior EPA Policy Makers: A Focus Group Study. U.S. EPA Office of Air Quality Planning and Standards.
- Chun, A. 1996. Strategies for Communicating Uncertainty to the Public. IBM Risk Conference Proceedings, October 31.
- Helsel, D.R. and R.M. Hirsch. 1993. *Statistical Methods in Water Resources*. Elsevier Science. Amsterdam.
- Slovic, P., B. Fischhoff, and S. Lichtenstein. 1979. Rating the Risks. *Environment* 21(3):14–20 and 36–39.
- Slovic, P. 1986. Informing and Educating the Public About Risk. *Risk Anal.* 6(4):403–415.
- Tufte, E.R. 1983. *The Visual Display of Quantitative Information*. Graphics Press. Cheshire, CT.
- U.S. EPA. 1989. *Risk Assessment Guidance for Superfund (RAGS): Volume I. Human Health Evaluation Manual (HHEM) (Part A, Baseline Risk Assessment)*. Interim Final. Office of Emergency and Remedial Response, Washington, DC. EPA/540/1–89/002. NTIS PB90-155581.
- U.S. EPA. 1991a. *Risk Assessment Guidance for Superfund (RAGS), Volume I: Human Health Evaluation Manual (HHEM)*, Part B, Development of Risk-Based Preliminary Remediation Goals. Office of Emergency and Remedial Response, Washington, DC. EPA/540/R-92/003. NTIS PB92-963333.
- U.S. EPA. 1991b. *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions*. Office of Solid Waste and Emergency Response, Washington, DC. OSWER Directive No. 9355.0-30.
- U.S. EPA. 1994. *Seven Cardinal Rules of Risk Communication*. Office of Policy Analysis. Washington, DC. EPA/OPA/87/020.
- U.S. EPA. 1998. *Superfund Community Involvement Handbook and Toolkit*. Office of Emergency and Remedial Response, EPA 540-R-98-007.
- U.S. EPA. 1999a. *Risk Assessment Guidance for Superfund: Volume I–Human Health Evaluation Manual. Supplement to Part A: Community Involvement in Superfund Risk Assessments*. EPA/540/R-98/042, March.
- U.S. EPA. 1999b. *Superfund Risk Assessment and How You Can Help: An Overview*. Videotape. September 1999 (English version) and August 2000 (Spanish version). English Version: EPA-540-V-99-003, OSWER Directive No. 9285.7-29B. Spanish Version (northern Mexican): EPA-540-V-00-001, OSWER Directive No. 9285.7-40. Available through NSCEP: 800.4909.198 or 513.489.8190.

U.S. EPA. 2000a. *El Superfund Hoy Día. La Estimación de Reiscos: Cómo Lograr La participación del la Comunidad. ¿Qué es la Estimación del Riesgo para la Salud Humana?* OSWER Directive No. 9200.2-26K. Enero. (fact sheet)

U.S. EPA. 2000b. *Superfund Risk Assessment and How You Can Help*. Videotape. (English version only). EPA-540-V-99-002, OSWER Directive No. 9285.7-29A. Available through NSCEP: 800.4909.198 or 513.489.8190, September.

U.S. EPA. 2001. *Early and Meaningful Community Involvement*. Office of Solid Waste and Emergency Response. Washington, DC. OSWER Directive No. 9230.0-99. October 12.

### ***Supplemental References Regarding Risk Communication and Public Perception***

Connelly, N.A. and B.A. Knuth. 1998. Evaluating Risk Communication: Examining Target Audience Perceptions About Four Presentation Formats for Fish Consumption Health Advisory Information. *Risk Anal.* 18:649–659.

Covello, V.T. 1987. Decision Analysis and Risk Management Decision Making: Issues and Methods. *Risk Anal.* 7(2):131–139.

Deisler, P.E. 1988. The Risk Management-Risk Assessment Interface. Last in a Five-Part Series on Cancer Risk Assessment. *Environ. Sci. Technol.* 22:15–19.

Fischhoff, B. 1995. Risk Perception and Communication Unplugged: Twenty Years of Process. *Risk Anal.* 15(2):137–145.

Fischhoff, B. 1998. Communicate unto others. *Reliab. Eng. Syst. Saf.* 59:63–72.

Fischhoff, B., A. Bostrom and M.J. Quadrel. 1997. Chapter 34. Risk Perception and Communication. In: *Oxford Textbook of Public Health*, Vol. 2, pp 987–1002. London: Oxford Univ. Press (Ed. R. Defels, et al.).

Hora, S.C. 1992. Acquisition of Expert Judgment: Examples from Risk Assessment. *J. Energy Eng.* 118(2):136–148.

Ibrekk, H. and M.G. Morgan. 1987. Graphical Communication of Uncertain Quantities to Non-Technical People. *Risk Anal.* 7:519–529.

Johnson, B.B. and P. Slovic. 1995. Presenting Uncertainty in Health Risk Assessment: Initial Studies of its Effects on Risk Perception and Trust. *Risk Anal.* 15:485–494.

Kaplan, S. 1992. ‘Expert Information’ Versus ‘Expert Opinions.’ Another Approach to the Problem of Eliciting/Combining/Using Expert Knowledge in PRA. *Reliab. Eng. Syst. Saf.* 35:61–72.

Morgan, M.G., A. Bostrom, L. Lave and C. J. Atman. 1992. Communicating Risk to the Public. *Environ. Sci. Technol.* 26(11):2048–2056.



Ohanian, E.V., J.A. Moore, J.R. Fowle, et al. Workshop Overview. 1997. Risk Characterization: A Bridge to Informed Decision Making. *Fundam. Appl. Toxicol.* 39:81–88.

Thompson, K.M. and D.L. Bloom. 2000. Communication of Risk Assessment Information to Risk Managers. *J. Risk Res.* 3(4):333–352.